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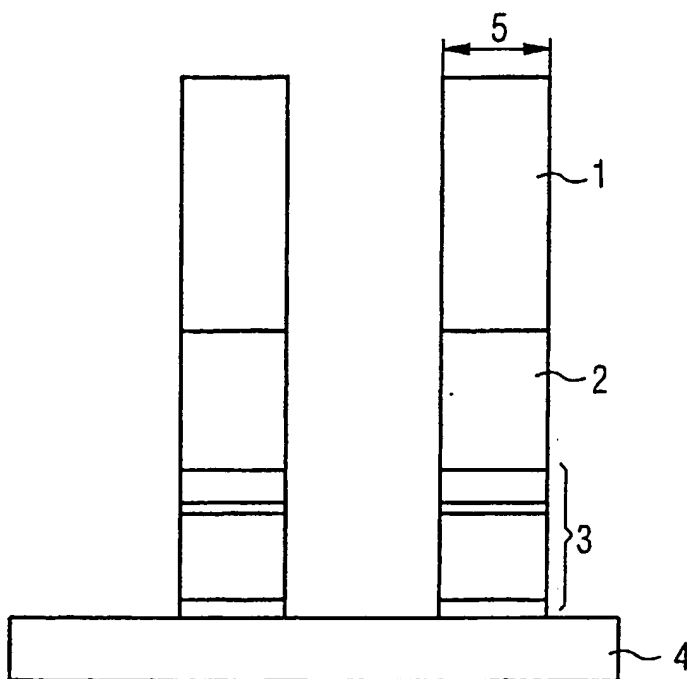
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(54) Title: METHOD FOR ETCHING A HARDMASK LAYER AND A METAL LAYER



(57) Abstract: The present invention relates to an improved insitu hardmask open strategy which is performed before carrying out a metal etch. The method for opening the hardmask (2) made of SiO<sub>2</sub>, Si<sub>3</sub>N<sub>4</sub> or SiON comprises the steps of providing a substrate having thereon at least one metal layer (3), a hardmask layer made of SiO<sub>2</sub>, Si<sub>3</sub>N<sub>4</sub> or SiON and a patterned photoresist layer overlying said hardmask layer (2), etching said hardmask layer (2) in a plasma etching process using an etchant source gas which comprises a fluorine containing gas and oxygen, wherein the plasma processing chamber used for etching the hardmask layer (2) is the same as the plasma processing chamber in which the at least one metal layer (3) is etched in another plasma etching process after the hardmask layer (2) has been etched.



WO 02/073682 A1

## Description

## Method for Etching a Hardmask Layer and a Metal Layer

- 5 The present invention relates to an insitu hardmask open strategy which is performed before carrying out a metal etch. The present invention is particularly suited for the processing of 300 mm silicon wafers.
- 10 Plasma assisted dry etching processes are widely used in the field of microelectronics and micromechanics. When features having a high aspect ratio are to be patterned as well as when rather etch resistant layers have to be patterned, very high demands must be met by the etching mask. In most cases
- 15 photoresist masks are insufficient in order to achieve the necessary etching selectivities. In these cases so called hard masks are used, the patterning of which again can become a severe problem.
- 20 Figure 1 illustrates an exemplary layer stack which is to be patterned by plasma etching. On a  $\text{SiO}_2$  base layer 4 which is usually provided on a semiconductor wafer, especially a silicon wafer, 10 nm of Ti, 400 nm of an alloy comprising 99,5 % Al and 0,5 % Cu, 5 nm of Ti and 40 nm of TiN are deposited as
- 25 a metall layer stack 3. Trenches having a width of approximately 140 nm are to be etched into the metal layer stack 3. In order to selectively etch these trenches, first, 180 nm of a SiON layer 2 are deposited as a hardmask material, followed by 490 nm of a generally used photoresist material 1. First,
- 30 as is shown in Figure 4, the pattern is photolithographically defined into the photoresist layer 1, then the SiON layer 2 is etched in a plasma etching process, and finally, the metal layer stack 3 is etched in another plasma etching process.
- 35 It has been rendered to be very advantageous if the hardmask layer, which is for example made of SiON, and the metal stack are etched insitu, which means that hardmask and metal stack

are etched in one single plasma processing chamber. In particular, when the hardmask and the metal stack are etched insitu, no additional plasma processing chamber and no additional wet clean chamber are necessary. Additionally, it is not necessary to move the silicon wafer from one plasma processing chamber to another thus reducing the processing time and cost.

As an etchant for etching the hardmask layer, usually a mixture of a fluorine containing gas such as  $\text{CF}_4$  or  $\text{CHF}_3$  and  $\text{Cl}_2$  is used. As an etchant for etching the metal layer stack, conventionally a mixture of a chlorine containing gas such as  $\text{BCl}_3$ ,  $\text{Cl}_2$  and, optionally,  $\text{N}_2$  and  $\text{CHF}_3$  is used.

As becomes apparent from Figure 4, a problem arises since the hardmask layer 2 is not vertically etched but assumes a tapered profile. As a consequence, as can be seen from Figure 5, after the metal layer stack etching step, the bottom of the trenches will have a much smaller width than the top of the trenches. Accordingly, when the metal etch is performed in order to define interconnection wirings, for example, the width thereof will be greater than that was lithographically defined in the photoresist layer. Generally speaking, the width denoted by reference numeral 5 in Figure 4 is generally referred to as the "CD" or "critical dimension".

It is an object of the present invention to achieve a better control of the CD. Especially it is an object to reduce the CD in an insitu hardmask open step.

30

According to the present invention, the above object is achieved by a method for etching a hardmask layer comprising  $\text{SiO}_2$  (silicon oxide),  $\text{Si}_3\text{N}_4$  (silicon nitride) or  $\text{SiON}$  (silicon oxynitride) and a metal layer comprising aluminum, the method comprising the steps of providing a substrate having thereon the at least one metal layer, the hardmask layer comprising  $\text{SiO}_2$ ,  $\text{Si}_3\text{N}_4$  or  $\text{SiON}$  and a patterned photoresist mask overlying

said hardmask layer in a plasma processing chamber, etching  
said hardmask layer in a plasma etching process using an  
etchant source gas which comprises a fluorine containing gas  
and oxygen, then etching the at least one metal layer in the  
5 same plasma processing chamber after the hardmask layer has  
been etched, then performing a plasma clean step to clean the  
walls of the plasma processing chamber.

As the inventors of the present invention found, in an insitu  
10 hardmask open process the CD of metal lines can be advantage-  
ously reduced if a small amount of oxygen is added to the  
etchant source gas used for etching the hardmask.

In particular, it was found that the metal etch step provides  
15 almost perpendicular walls whereas the taper is mainly indu-  
ced by the hardmask opening step. More specifically, when  
performing any anisotropic plasma etching process, the etch-  
ant source gas will also attack the photoresist layer whereby  
polymers will be produced which will then be deposited at the  
20 sidewalls of the trench. For example, during the metal etch  
step, a thin polymeric film will be formed on the trench  
walls so as to prevent the walls from being further etched,  
whereas the thin polymeric layer deposited on the trench bot-  
tom will be destroyed by ion bombardment during the plasma  
25 etching process. In contrast, due to the specific plasma con-  
ditions during the hardmask open step, the polymeric layer  
will be deposited onto the trench walls so as to produce a  
tapered shape.

30 By adding a small amount of oxygen, for example 5 to 10 sccm  
(cubic centimeters per minute under standard conditions) if  
100 sccm of a fluorine containing gas are fed, this tapered  
shape can be avoided, whereby a vertical etching profile is  
achieved. Consequently, the CD can be better controlled and  
35 further be reduced.

Moreover, the present invention provides a method for patterning a metal layer stack comprising at least one metal layer on a substrate, comprising the steps of the method according as defined above, and the step of etching said at least one  
5 metal layer in said plasma processing chamber in another subsequent plasma etching process. Both etching processes are performed within the same plasma processing chamber preferably without breaking the vacuum. The plasma etching process for etching the metal layer uses a different etch gas  
10 composition when compared to the hardmask etch step.

A problem which may arise when the insitu etching process for etching the hardmask layer and the metal stack including a layer containing aluminium is performed a plurality of times  
15 so as to process several wafers is that the aluminium etched will be deposited on the plasma processing chamber walls. If thereafter a new wafer is introduced into the plasma processing chamber and a hardmask etching step using oxygen is performed, the deposited aluminium will react with the oxygen to  
20 form aluminium oxide which is very brittle and, thus, will peel off the plasma processing chamber walls so as to fall onto the wafer and cause unwanted impurities on the wafer surface.

25 This problem can be solved if the plasma processing chamber is cleaned by an additional plasma cleaning step using for example an inert gas or oxygen as a cleaning gas, the cleaning step being performed after the metal etch step.

30 Using this plasma cleaning step, all the polymers and all the aluminium which have been deposited on the plasma processing chamber walls during the metal etch step will be removed before the next oxygen containing hard mask open step of the next wafer will start.

35

In summary, the present invention provides the following advantages:

- The hardmask layer and the metal stack are etched insitu, that is in one single plasma processing chamber and without breaking the vacuum lock. Accordingly, only one plasma etching tool and only one wet cleaning device are necessary. Consequently, processing cost can be reduced. Moreover, since the vacuum is maintained and the wafer need not be transferred from one plasma processing chamber to another, the processing time can be considerably reduced.

10

- The tapered etching profile in the hardmask layer is avoided. Thus, vertical walls can be etched in the hardmask layer and the metal layer stack, whereby the CD can be remarkably reduced and be better controlled. In particular, the CD defined in the photoresist layer corresponds to the CD etched into the metal layer stack.

15

Figure 1 shows a metal layer stack having a hardmask layer and a patterned photoresist layer thereon, the metal layer stack being deposited on a SiO<sub>2</sub> base layer;

20

Figure 2 shows the metal layer stack of Figure 1 after performing the hardmask open step of the present invention;

Figure 3 shows the metal layer stack of Figure 2 after selectively etching the metal layer stack;

25

Figure 4 shows the metal layer stack of Figure 1 after performing the hardmask open step according to the method of the prior art;

Figure 5 shows the metal layer stack of Figure 4 after selectively etching the metal layer stack; and

30

Figure 6 shows an exemplary plasma processing chamber.

In Figure 1, on a SiO<sub>2</sub> (silicon oxide) base layer 4 which is usually provided on a semiconductor wafer, a metal layer stack 3 comprising 10 nm of Ti (titanium), 400 nm of an alloy comprising 99,5 % Al (aluminium) and 0,5 % Cu (copper), 5 nm of Ti and 40 nm of TiN (titanium nitride) are deposited.

35

Trenches having a width of approximately 140 nm are to be etched into the metal layer stack 3. The CD 5 also is 140 nm. In order to selectively etch these trenches, first, a layer 2 of 180 nm of SiON (silicon oxynitride) are deposited as a  
5 hardmask material, followed by 490 nm of a generally used photoresist material 1.

According to the present invention, the hardmask opening step and the metal etching step are performed in a single plasma  
10 processing chamber in two different steps using different etchants. Accordingly, the two steps are performed subsequently without breaking vacuum lock.

The plasma processing apparatus that can be used for carrying  
15 out the present invention may be any known plasma processing apparatus such as devices for dry etching, plasma etching, reactive ion etching or electron cyclotron resonance etching.

For example, the process of the present invention may be per-  
20 formed in a transmission coupled plasma etching apparatus (TCP) which is shown in Figure 6. In such an etching apparatus the energy for sustaining the plasma is inductively coupled to the reactor. However, in a different plasma etching apparatus, this energy could be also capacitively coupled.

25

The plasma processing system in Figure 6 includes a plasma processing chamber 6 having a gas inlet 9 for feeding the etchant source gas. In the present example, this gas inlet 9 is implemented as a gas dispensing apparatus having a shower  
30 head configuration. However, the gas inlet can be implemented in any other suitable manner. Moreover, there is provided a top electrode 7 which takes the form of a coil. The coil electrode 7 is energized by a RF (radio frequency) generator 8 via a matching network (not shown) as is conventional. The  
35 wafer 11 is introduced into the plasma processing chamber 6 and disposed on an electrostatic chuck 13 which acts as an electrode and is preferably biased by a RF generator 10.

However, the chuck 13 may also be implemented in a different manner being connected to the RF generator 10. Helium cooling gas may be introduced under pressure through port 12 between chuck 13 and wafer 11 so as to act as a heat transfer medium for accurately controlling the temperature of the wafer during processing to ensure uniform and reproducible etching results. In the present example, a wafer temperature of 35°C is maintained.

- 10 The RF generators 8, 10 through coil electrode 7 and chuck 13 are used to generate a plasma in the etchant source gas within the plasma processing chamber 6 in order to etch the wafer 11.
- 15 The by-product gases formed during the plasma etching process are exhausted by an exhaust line 14 which is connected with a suitable pump for maintaining the desired vacuum conditions. Typically, the chamber walls are grounded.
- 20 After introducing the wafer 11 into the plasma processing chamber 6, various stabilisation steps as generally known in the art are performed, in which the etchant source gases are fed into the plasma processing chamber without plasma so as to provide stable process conditions and to set the pressure as well as the desired gas flow rates. Thereafter, the plasma is ignited, a bias is applied to the chuck and then, a hard-mask open step is performed.

As an etchant source gas, according to the present invention, a mixture of a fluorine containing gas such as  $\text{CF}_4$  (Tetrafluoromethane) or  $\text{CHF}_3$  (Trifluoromethane), Argon and a small amount (approximately 5 to 20 % based on the flow rate of the fluorine containing gas) of oxygen is used. In particular, typical flow rates to be employed are 100 sccm of  $\text{CF}_4$ , 150 sccm of Argon and 5 to 20 sccm of  $\text{O}_2$  (oxygen). The pressure prevailing in the plasma processing chamber is in the order of 1 to 1,5 Pa. The RF power applied to the top electrode 7

is set to approximately 600 to 1000 W, and the RF power applied to the chuck 13 is set to approximately 150 to 300 W which are preferred settings for transformer coupled plasma (TCP) tools. The radio frequency employed is 13.56 MHz.

5

As the inventors of the present invention found out, the addition of Argon to the etchant source gas additionally decreases the CD, since reaction products are carried off more quickly. This is also the case if an etchant source gas of a  
10 fluorine containing gas without oxygen is used. In particular, a flow rate of Argon which is greater than that of the fluorine containing gas, for example a ratio of 1,5 between Argon gas flow rate and fluorine containing gas flow rate, has provided excellent results.

15

After the hardmask opening step, various gas rinsing steps can be performed, in which inert gases such as Argon or N<sub>2</sub> (nitrogen) are fed so as to remove residual gases from the former etching process from the plasma processing chamber.  
20 Moreover, or alternatively, stabilisation steps as described above can be performed.

If necessary, breakthrough steps are also performed, in which the oxidized surface of a metal layer to be etched is removed  
25 by an anisotropic etching step.

Thereafter, another plasma etching process is performed so as to etch the metal layer stack. The term „another plasma etching process“ means that an etchant source gas which is  
30 different from the etchant source gas used for etching the hardmask layer is used. For etching the metal layer stack, a chlorine containing gas mixture such as BCl<sub>3</sub> (boron trichloride) and Cl<sub>2</sub> (chlorine) and, optionally, N<sub>2</sub> and CHF<sub>3</sub> is used as an etchant source gas.

35

Moreover, various overetch steps as generally known in the art are performed.

After that, the wafer 11 is removed from the plasma processing chamber and, then, optionally, after introducing a dummy wafer for protecting the chuck, a plasma cleaning step using  
5 oxygen or an inert gas such as  $N_2$  can be performed so as to clean the walls of the plasma processing chamber 6. Alternatively, the processed wafer 11 can also be removed after plasma cleaning the processing chamber 6.

10 The wafer 11 is then transferred to a resist-strip chamber, wherein the remaining photoresist 1 is stripped. Thereafter, the wafer is processed in a conventional manner.

After the plasma cleaning step, which can as well be omitted,  
15 the next wafer 11 to be processed can be introduced into the plasma processing chamber 6.

- 1 photoresist layer
- 2 SiON layer
- 3 metal stack
- 4 SiO<sub>2</sub> base layer
- 5 5 critical dimension
- 6 plasma processing chamber
- 7 top electrode
- 8 RF generator for top electrode
- 9 gas inlet
- 10 10 RF generator for chuck
- 11 wafer
- 12 port
- 13 chuck
- 14 exhaust line
- 15

## Claims

1. A method for etching a hardmask layer (2) which comprises  
5 silicon oxide, silicon nitride or silicon oxynitride and at least one metal layer (3) which comprises aluminum, the method comprising the steps of:
  - providing a substrate (11) having thereon the at least one metal layer (3), the hardmask layer (2) comprising silicon  
10 oxide, silicon nitride or silicon oxynitride and a patterned photoresist layer (1) overlying said hardmask layer (2) in a plasma processing chamber (6);
  - etching said hardmask layer (2) in a plasma etching process using an etchant source gas which comprises a fluorine con-  
15 taining gas and oxygen,
  - then etching the at least one metal layer (3) in the same plasma processing chamber (6) after the hardmask layer (2) has been etched,
  - then performing a plasma clean step to clean the walls of  
20 the plasma processing chamber (6).
2. The method according to claim 1, wherein the fluorine containing gas comprises one of  $\text{CF}_4$  and  $\text{CHF}_3$ .
- 25 3. The method according to claim 1 or 2, wherein the etchant source gas additionally comprises Argon.
4. The method according to any of the preceding claims, wherein the flow rate of oxygen is 5 to 10 % based on the  
30 flow rate of fluorine containing gas.
5. The method according to any of claims 1 to 4, wherein the step of etching said at least one metal layer in said plasma processing chamber (6) is performed in another subsequent  
35 plasma etching process using a different composition of etch gases.

6. The method according to one of claims 1 to 5, wherein the plasma cleaning step is performed using an inert gas or oxygen as a cleaning gas.

5 7. The method according to claim 6, wherein the plasma cleaning step is performed after the metal layer (3) has been etched.

10 8. The method according to one of claims 1 to 7, wherein the step of etching the hardmask layer (2) performs an etching of the hardmask layer (2) with respect to the patterned photoresist layer.

15 9. The method according to claim 8, wherein the photoresist layer (1) is present during the step of etching the metal layer (3).

1/3

FIG 1

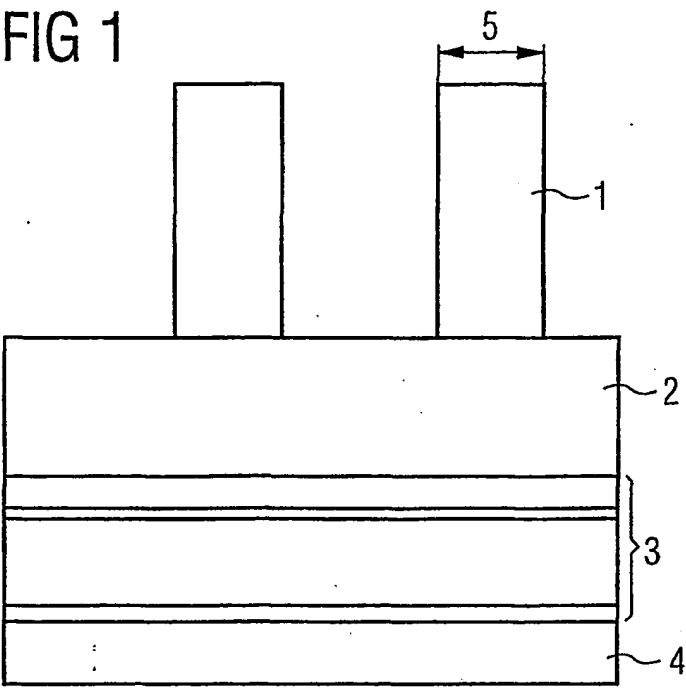
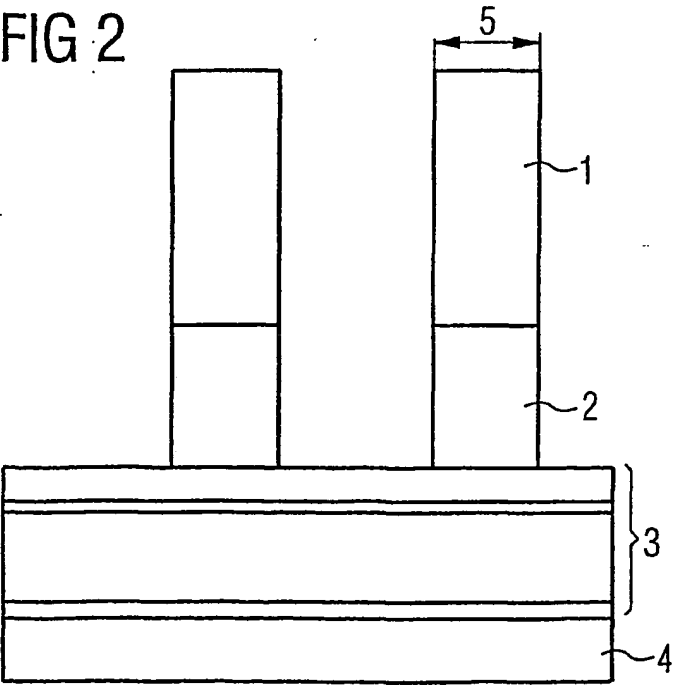


FIG 2



2/3

FIG 3

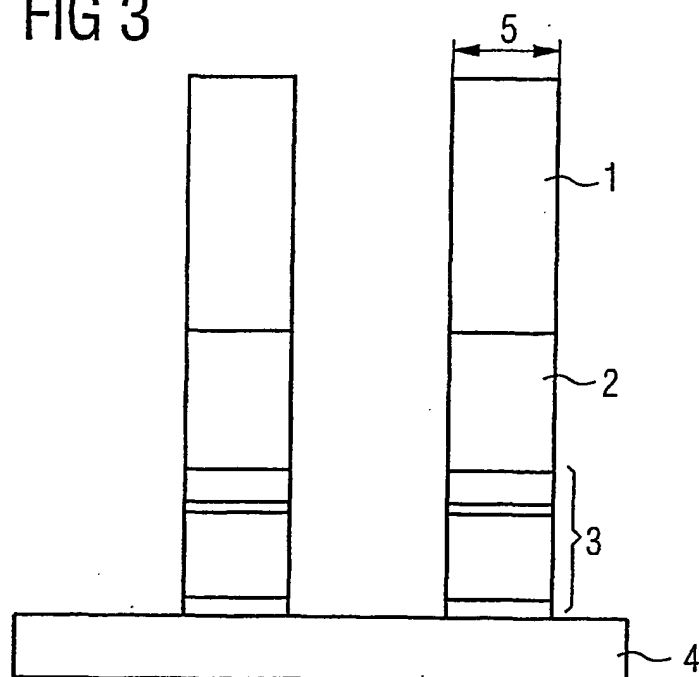
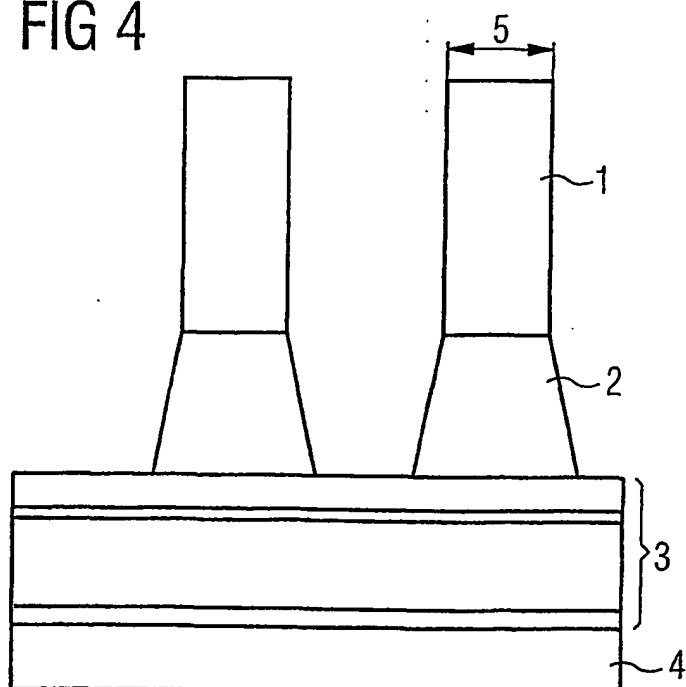


FIG 4



3/3

FIG 5

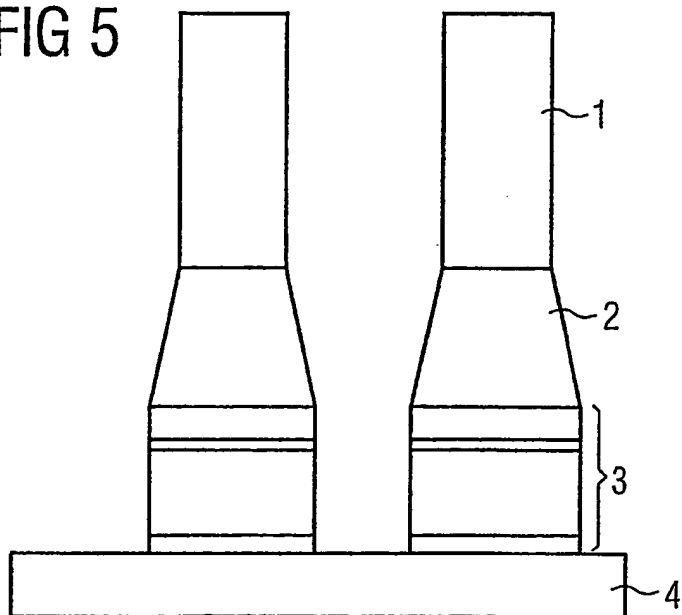
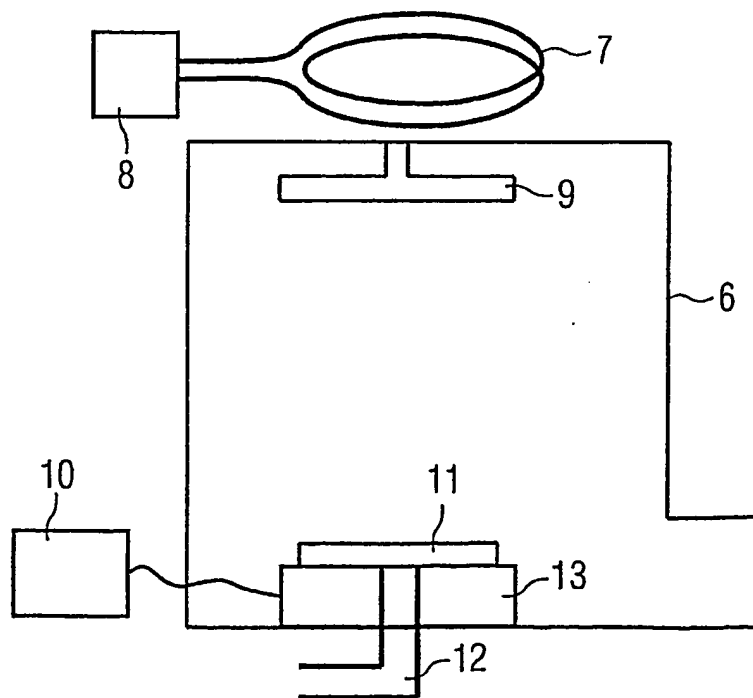


FIG 6



## INTERNATIONAL SEARCH REPORT

International Application No

PCT/EP 02/02030

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 7 H01L21/3213

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6 159 863 A (CHEN ET AL) 12 December 2000 (2000-12-12) abstract; figure 4	1-9
Y	WO 96 27899 A (IBM) 12 September 1996 (1996-09-12) page 2, paragraph 3 -page 3, paragraph 1	1-9
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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